ANSTO/E680

AUSTRALIAN NUCLEAR SCIENCE AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS RESEARCH LABORATORIES

TRITIUM ACTIVITY IN AUSTRALIAN RAINWATER 1962-1986

by

G.E. CALF

JULY 1988

ISBN 0 642 59887 8

ISSN 1030-7745

AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS RESEARCH LABORATORIES

TRITIUM ACTIVITY IN AUSTRALIAN RAINWATER 1962-1986

by

G.E. CALF

ABSTRACT

Atmospheric tritium precipitated in rainfall has been measured since 1962 in samples from a network of Australian monitoring stations. Atmospheric thermonuclear bomb tests have injected into the atmosphere about 350 kg of tritium, mostly into the northern hemisphere's troposphere and stratosphere, causing atmospheric concentrations of tritium to reach peak values of 50 to 100 tritium units (TU) in the southern hemisphere. Tritium from underground testing has not contributed significantly to the amounts in the atmosphere or in surface waters. In Australia, peak concentrations of precipitated tritium were observed in 1962, 1964 and 1969. The tritium activity in rainwater for all Australian stations decreased after 1969. Radioactive decay of bomb tritium will decrease the tritium budget to the natural level by the early 1990s in Australian precipitation.

ISBN 0 642 59887 8
ISSN 1030-7745

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

AUSTRALIA; EARTH ATMOSPHERE; GROUND WATER; RADIOACTIVITY; RAIN; RAIN WATER; TRITIUM; THERMONUCLEAR EXPLOSIONS.

EDITORIAL NOTE

The Australian Nuclear Science and Technology Organisation replaced the Australian Atomic Energy Commission on 27 April 1987. Reports issued after April 1987 have the prefix ANSTO with no change of the symbol (E, M, S or C) or numbering sequence.

CONTENTS

1. INTRODUCTION

Tritium (hydrogen-3) can be produced by a large number of natural and artificial processes. The interaction of cosmic radiation with atmospheric oxygen and nitrogen in the troposphere is the most important natural process (**reactions 1-3**) and the detonation of thermonuclear devices (**reaction 4**) is the most important artificial process:

$$ {}^{14}_{7}N + n \rightarrow {}^{3}_{1}H + {}^{12}_{6}C \quad (1)$$

$$ {}^{16}_{8}O + p \rightarrow {}^{3}_{1}H + {}^{14}_{8}O \quad (2)$$

$$ {}^{16}_{8}O + \alpha \rightarrow {}^{3}_{1}H + {}^{17}_{9}F \quad (3)$$

$$ a_1\,{}^{6}_{3}Li + a_2\,{}^{2}_{1}H \rightarrow a_3\,{}^{4}_{2}He + a_4\,{}^{3}_{2}He + a_5\,{}^{1}_{1}H + a_6\,n + a_7\,{}^{3}_{1}H \quad (4)$$

where parameters a_1- - - - - - - -a_7 are dependent on the weapon design.

Before the atmospheric testing of nuclear bombs, the total amount of tritium in the biosphere was in equilibrium, that is, its global decay rate and global production were equal. From the few available samples from pre-bomb times, and from estimates of the cosmic-ray flux and its interactions, it has been estimated that the natural production rate is 0.5 ± 0.3 nuclei per cm^2 of earth surface per second [Nir *et al.* 1966] or 1.5×10^{17} Bq y^{-1} [Eisenbud *et al.* 1978] and the equilibrium quantity was 2.6×10^{18} Bq or 7.3 kg.

Large amounts of tritium are also produced by ternary fission of uranium-235 and plutonium-239 in nuclear reactors. About one in every ten thousand fission events yields a tritium atom which may be released at the nuclear power plant or may not be released in significant amounts until the fuel rods are reprocessed. Most modern nuclear plants release very little tritium to the local atmosphere.

Tritium has a half-life of 12.43 years [Unterweger *et al.* 1980] and decays to helium-3 with the emission of a β^- particle of maximum energy 18.6 keV. The very small amount of tritium in natural waters led to the definition of the tritium unit (TU), which corresponds to an atomic ratio of one atom of tritium for 10^{18} atoms of hydrogen. This unit is sometimes referred to as the tritium ratio (TR). The corresponding radioactivity in water containing 1 TU is 0.118 Bq kg^{-1} (3.19 pCi kg^{-1} or 7.2 dpm kg^{-1} in the previously used non-SI units, where dpm refers to [radioactive] disintegrations per minute).

2. SAMPLING PROGRAMS

During the past 25 years, a large number of rainwater samples from Australian stations has been analysed. Monthly samples were collected from a world-wide network of rain sampling stations, operated by the International Atomic Energy Agency (IAEA) and the World Meteorological Organisation [IAEA, 1969, 1970, 1971, 1973]. The Australian Atomic Energy Commission (renamed the Australian Nuclear Science and Technology Organisation in April 1987) has collected and analysed monthly rainwater samples from the Australian network stations since 1970 [Calf *et al.* 1976, 1977; Calf and Stokes 1979, 1981, 1983, 1985, 1987]. **Appendix A** shows precipitation and tritium data for the Australian network from 1962 to 1986.

3. COSMIC-PRODUCED TRITIUM

Natural tritium is produced in larger quantities at high latitudes owing to the minor magnetic deviation of charged cosmic particles (alpha and protons) which produce secondary neutrons by interaction with gas molecules high in the atmosphere. After formation, tritium is rapidly oxidised into water, then removed from the troposphere by precipitation [Fontes 1985]. The natural activity of tritium in precipitation is estimated to be between 20 and 25 TU at high latitudes and about 4 TU in equatorial regions [Gat 1980].

4. BOMB TRITIUM

The yield of tritium in the fission process is approximately 10^{-2} per cent [Albenesius 1959]. The production of 1 Mt of energy by fission requires 1.4×10^{26} fissions and produces about 0.07 g (2.6×10^{13} Bq) of tritium [Miskel 1973]. The yield of tritium from thermonuclear explosions (fusion) is between 0.7 and 5 kg per megaton [Miskel 1964]. This quite wide range is due to variations in design and performance of individual devices.

The thermal convection which occurs during atmospheric tests transports a large percentage of radioactive nuclides and debris into the stratosphere. A world-wide pattern of global or stratospheric fallout is produced, but it is largely confined to the hemisphere in which the detonation occurred since there is very little mixing of air between the hemispheres, because of the laminar structure of the air masses and the monodirectional winds which induce a general motion of rotation at the latitude of injection [Fontes 1985].

Most bomb tests were conducted north of the equator, the subsequent tritium yield being injected into the northern hemisphere's troposphere. The residence time of tritium in the troposphere is 21 to 40 days, whereas it has a residence time in the stratosphere of a few years [Eisenbud *et al.* 1979].

The first thermonuclear explosion occurred on 31 October 1952. Since that time, tests have included both fission and fusion weapons; 521 nuclear devices were exploded between 1945 to 1981 [Morishima *et al.* 1985]. A voluntary moratorium existed from 30 October 1958 to 1 September 1962. The total yield from all nuclear weapon tests from 1945 to 1962 is summarised in **table 1** [Izrael and Stukin 1967]. The total tritium produced in these tests was approximately 1.2×10^{20} Bq (333 kg).

TABLE 1

YIELDS FROM NUCLEAR WEAPON TESTS

Years	Number of Nuclear Explosions	Total Yield (Mt)	Fission Yield (Mt)	Fusion Yield (Mt)
1945-1958	233	170	92	78
1959-1962	113	510	190	320

Injections of tritium into the biosphere occurred as two main pulses, one from the 78 Mt of fusion in 1955 and the other from the 320 Mt of fusion in 1962. Shortly after the largest nuclear tests in the early '60s, atmospheric concentrations of tritium peaked at 50 to 100 TU in the southern hemisphere, with slightly higher values in some tropical regions, and 500 to more than 10 000 TU in the northern hemisphere.

Atmospheric testing was resumed by the USSR in September 1961 and underground testing by the United States the same month. The limited test ban treaty took effect in 1962. Since this date, only France and China have carried out atmospheric tests, totalling 64 nuclear explosions up to 1980 and accounting for about 23 Mt of yield. France, conducted its first nuclear tests in 1960 and has conducted underground tests since 1975. The People's Republic of China exploded its first weapon in 1964. India, the sixth nation known to have tested nuclear weapons, conducted its first test in 1974. The total tritium produced by these tests is approximately 1.1×10^{19} Bq (30 kg).

From 1962 to 1969, only rainwater from six stations was analysed by the IAEA for tritium activity. Consequently, interpretation of peaks in tritium levels for any of these years is uncertain as one event can greatly influence the yearly weighted mean. Results indicate that tritium from the 1962 atmospheric tests was observed in the 1964 peak in Australian rainwater tritium activity, as shown in **figures 1** and **2**. The 1969 tritium peak in Australian rainwater is probably due to the French tests at the Mururoa test site in the Pacific Ocean (**figures 1** and **2**).

It should be noted that only atmospheric detonations are significant as tritium from underground testing has not added appreciably to the amount of tritium in the atmosphere and surface waters.

5. TRITIUM IN PRECIPITATION

In general, tritium concentration in precipitation is a factor of between 5 and 20 higher in the northern hemisphere than in the southern hemisphere. Lowest concentrations are found about 10° south of the equator. Coastal areas have much lower tritium activities than inland areas [Ferronsky and Palyakov 1982]. In Australia, the same situation occurs, as is shown by comparing tritium rainwater activities at Alice Springs and Brisbane (**figure 2**). Seasonal variations of tritium in rainwater at any station in the network are similar to those shown in the curve in **figure 3**, in which the tritium concentrations of monthly rainwater samples are

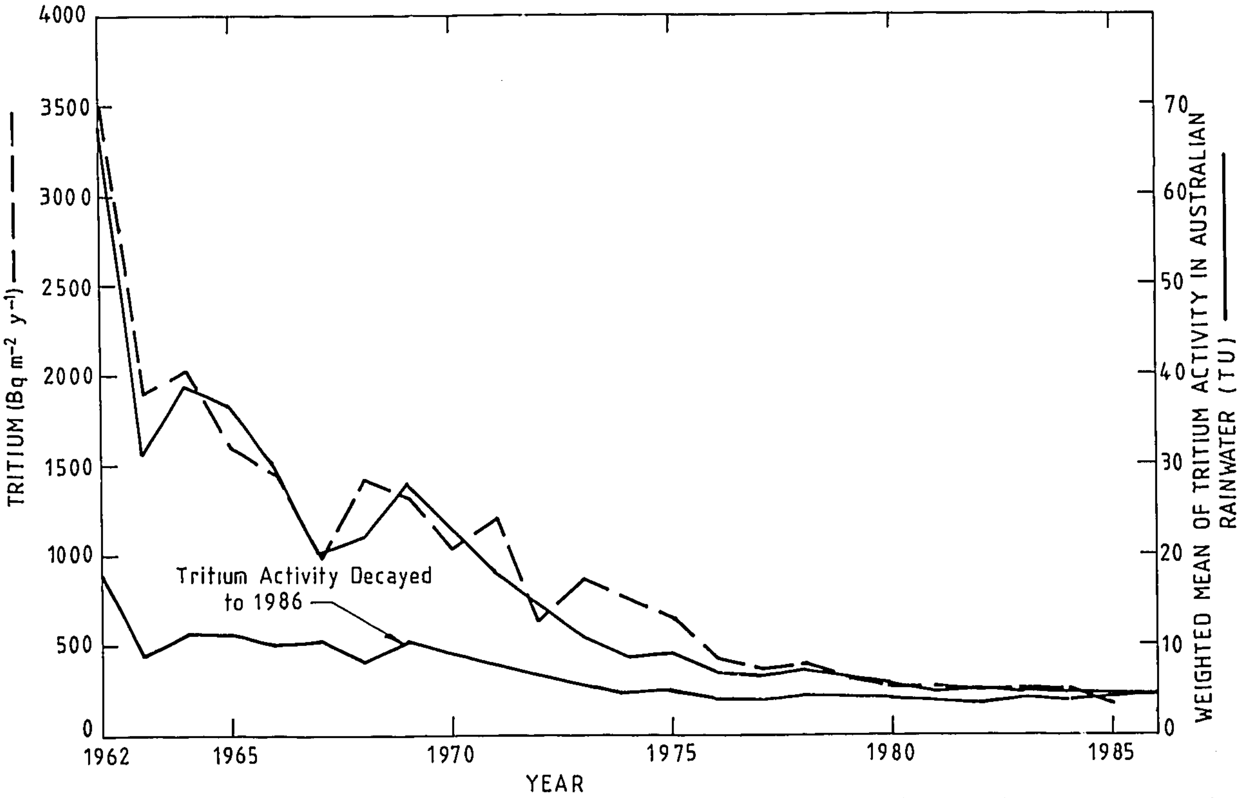

Figure 1 Graph of the weighted mean of tritium activity in Australian rainwater (1962 to 1986). The residual activity of rainwater tritium decayed to 1986 is shown. The amount of tritium in precipitation as Bq m^{-2} y^{-1} is also plotted.

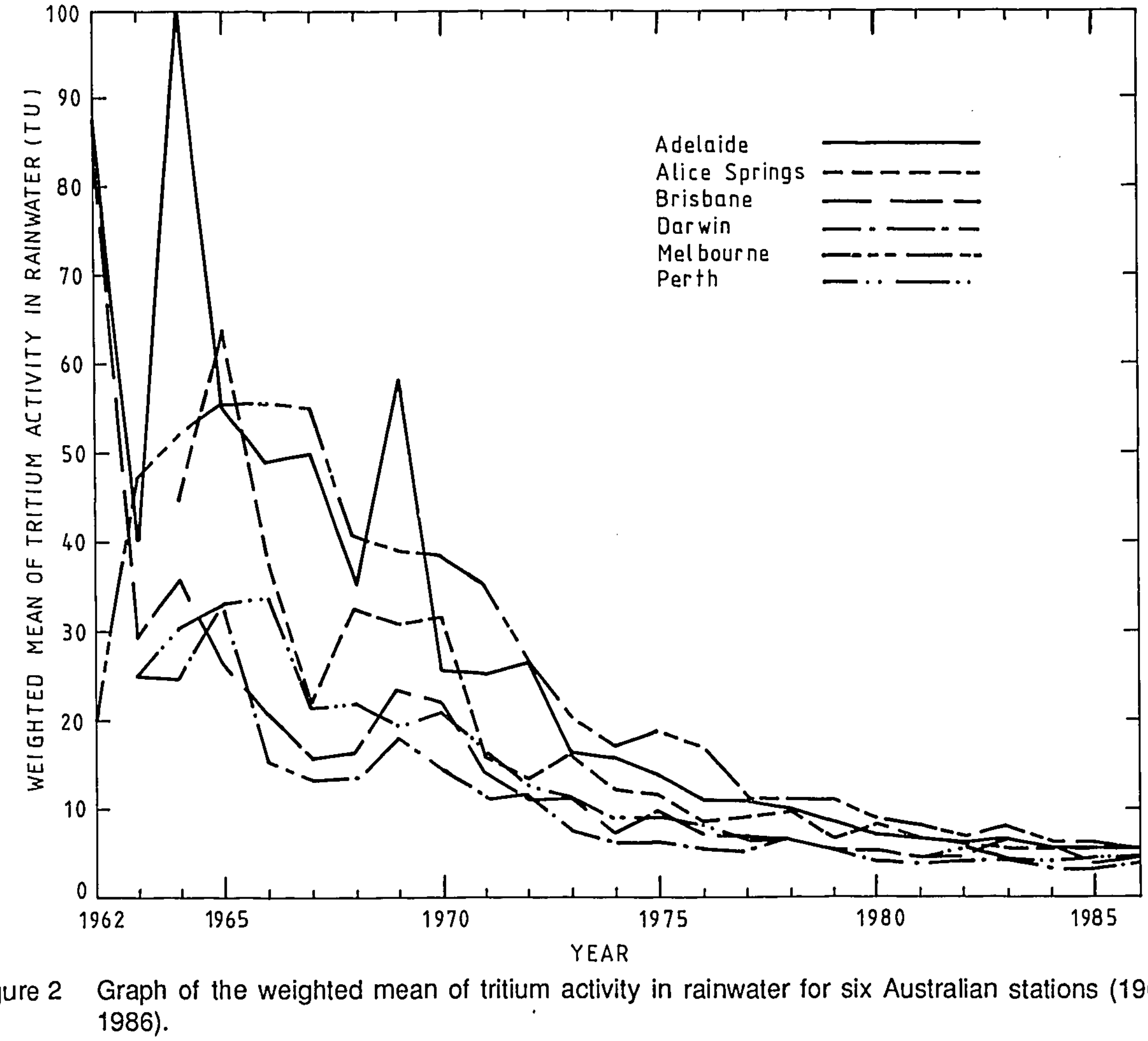

Figure 2 Graph of the weighted mean of tritium activity in rainwater for six Australian stations (1962 to 1986).

plotted for Brisbane in Queensland.

The mechanisms of tritium movement from the stratosphere to the troposphere are not fully understood. Several processes have been suggested such as diffusion through the tropopause (the transition layer between the troposphere and the stratosphere at a height of about 12 km) and the sowing of convective clouds which penetrate the stratosphere [Fontes 1985]. The main transfer probably occurs through tropopause discontinuities or extrusions of the tropopause. These discontinuity zones appear seasonally at the end of winter when polar and equatorial tropopauses begin their opposite migration towards the pole and equator respectively. The result is a spring leak [Karol 1970] which is approximately three times the average annual weighted activity (**figure 3**). The tropopauses move back at the end of autumn and give rise to a winter valley with half the annual average activity.

In **table 2** is shown the weighted mean of rainfall for the years 1962 to 1985, calculated from the yearly precipitation totals for the 99 Australian rainfall districts. From the weighted mean of tritium activity in each year's rainfall, the amount of tritium precipitated annually is expressed in both Bq m^{-2} y^{-1} and g y^{-1}.

TABLE 2

TRITIUM FALLOUT OVER THE AUSTRALIAN CONTINENT

Year	Weighted Mean of Rainfall (mm)	Weighted Mean of Tritium Activity in Precipitation (TU)	Tritium in Precipitation	
			(Bq m^{-2} y^{-1})	(g y^{-1})
1962	439	67.5	3497	75.4
1963	513	31.2	1887	25.6
1964	444	38.8	2033	43.9
1965	370	36.5	1598	34.5
1966	405	30.1	1438	31.0
1967	413	20.4	994	21.4
1968	544	22.1	1419	30.6
1969	416	26.9	1320	28.5
1970	386	22.6	1029	22.2
1971	570	17.8	1197	25.8
1972	360	14.3	607	13.1
1973	666	11.0	864	18.6
1974	742	8.7	762	16.4
1975	588	9.1	631	13.6
1976	514	6.9	418	9.0
1977	456	6.5	350	7.5
1978	508	7.0	420	9.1
1979	440	6.0	312	6.7
1980	423	5.4	270	5.8
1981	519	4.7	288	6.2
1982	403	5.0	238	5.1
1983	490	4.8	278	6.0
1984	543	4.3	276	6.0
1985	402	4.2	199	4.3

In the northern hemisphere, radioactive decay will decrease the tritium budget to the natural level approximately by the year 2030 [Eisenbud *et al.* 1979]. **Figure 4** shows that the natural level of 4 TU will be found in Australian rainwater by the early 1990s.

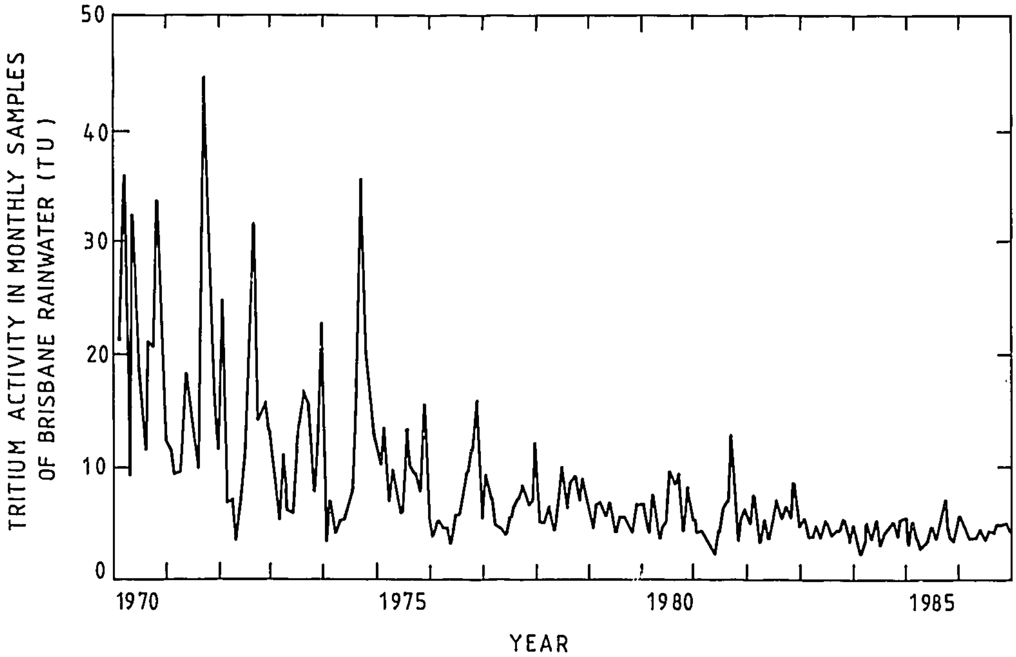

Figure 3 Graph of the tritium activity in monthly samples of rainwater collected at Brisbane, 27 28S 153 02E (1962 to 1986).

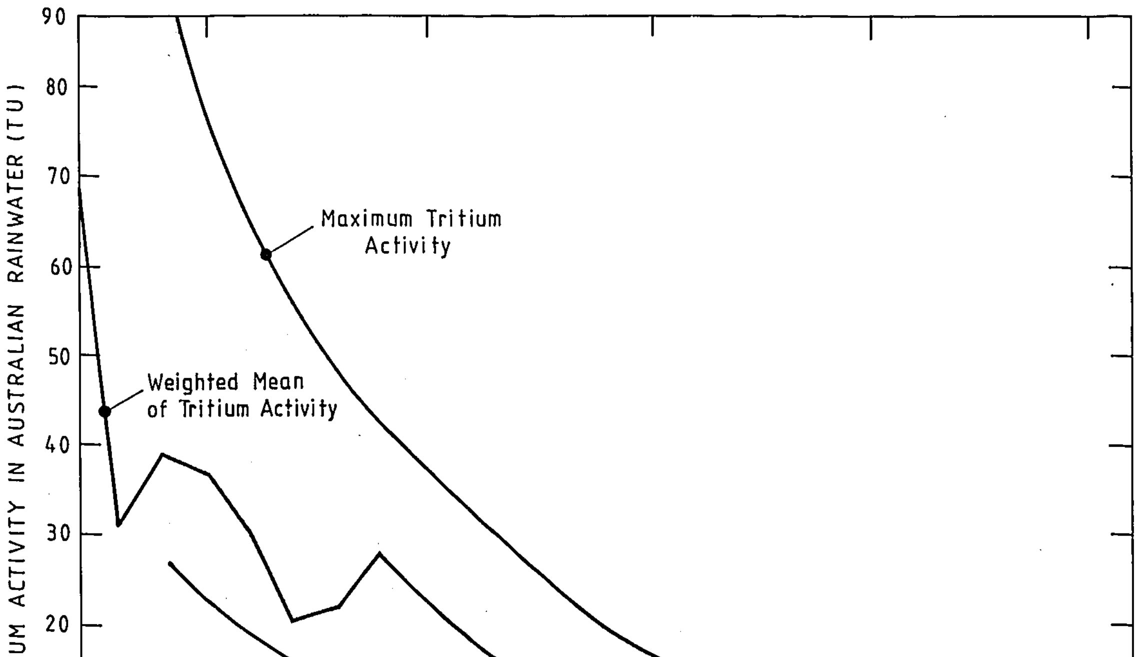

Figure 4 Graph of the variation of tritium activity in Australian rainwater samples (1964 to 1986).

6. THE USE OF TRITIUM IN AUSTRALIAN GROUNDWATER STUDIES

Tritium levels are often used as a means of evaluating water residence times. The last pre-bomb precipation occurred in 1951-1952 when the tritium activity was 4 to 10 TU. By 1986, this activity range had decayed to 1 to 2 TU (**figure 1**).

The detailed interpretation of tritium activity in groundwater is usually so complex [Suess 1969] and almost always ambiguous, that the tendency is to avoid designating specific ages for groundwater based on tritium analyses. The most difficult and critical dating problem is to establish the original input of tritium as a function of time. Because of the decrease in tritium in precipitation since the early '70s, recent recharge may contain less tritium than waters precipitated some years before (**figures 1** and **4**). Furthermore, the mixing of old water containing no tritium with water precipitated in the '60s may give rise to a higher tritium activity than occurs in present-day recharge. A practical rule for identifying Australian groundwater is shown in **table 3**.

TABLE 3

INTERPRETATION OF TRITIUM ACTIVITY IN AUSTRALIAN GROUNDWATER
(Mixing within aquifers is assumed to be negligible)

Activity (TU)	Interpretation
Less than 0.2	Water is older than 50 years.
Less than 2.0	Water is older than 25 years.
Between 2 and 10	Interpretation is difficult; water is probably modern.
Between 10 and 20	Water is 15 to 25 years old.
More than 20	Probably related to water from peak fall-out period 1960-1964.

7. CONCLUSIONS

Australian rainwater samples exhibited the following characteristics:

(a) The yearly maximum tritium activity was observed around the period of late spring to early summer.

(b) Maximum annual tritium activity was observed in 1962. Northern hemisphere stations observed their maximum in 1963 [Morishima *et al.* 1985].

(c) Continental stations always show higher weighted means of tritium activity than maritime stations. This effect is usually attributed to the dilution of high tritium content water vapour with low tritium content water vapour evaporated from the ocean surface.

(d) The tritium activity in rainwater for all Australian stations decreased after 1969.

8. REFERENCES

Albenesius, E.L. [1959] - Tritium as a product of fission. *Phys. Rev. Lett.*, **3**:274-275.

Calf, G.E., Seatonberry, B.W., Smith, L.W., Stokes, R.C. [1976] - AAEC tritium list No. 1 1970-1974. AAEC/E377.

Calf, G.E., Smith, L.W., Stokes, R.C. [1977] - AAEC tritium list No. 2 1975-1976. AAEC/E414.

Calf, G.E., Stokes, R.C. [1979] - AAEC tritium list No. 3 1977-1978. AAEC/E473.

Calf, G.E., Stokes, R.C. [1981] - AAEC tritium list No. 4 1979-1980. AAEC/E519.

Calf, G.E., Stokes, R.C. [1983] - AAEC tritium list No. 5 1981-1982. AAEC/E569.

Calf, G.E., Stokes, R.C. [1985] - AAEC tritium list No. 6 1983-1984. AAEC/E610.

Calf, G.E., Stokes, R.C. [1987] - ANSTO tritium list No. 1 1985-1986. ANSTO/E661.

Eisenbud, M., Bennett, B., Blanco, R.E., Compere, E.L., Goldberg, E., Jacobs, D.G., Koranda, J., Moghissi, A.A., Rust, J.H., Soldat, J.K. [1979] - In *Behaviour of Tritium in the Environment.* IAEA, Vienna, pp.585-588.

Ferronsky, V.I., Palyakov, V.A. [1982] - Environmental Isotopes in the Hydrosphere (translated from Russian). John Wiley & Sons, New York.

Fontes, J-Ch. [1985] - Hydrology in the service of man. *Memoires of the 18th Congress of the International Association of Hydrogeologists.* Cambridge, UK, pp.118-154.

Gat, J.R. [1980] - The isotopes of hydrogen and oxygen in precipitation. In *Handbook of Environmental Isotope Geochemistry.* Vol. 1. *The Terrestrial Environment* (eds. Fritz, P., Fontes, J-Ch.). Elsevier, New York, pp.21-47.

IAEA [1969] - Environmental Isotope Data No. 1 - World Survey of Isotope Concentration in Precipitation (1953-1963). *Technical Report Series* No. 96. IAEA, Vienna.

IAEA [1970] - Environmental Isotope Data No. 2 - World Survey of Isotope Concentration in Precipitation (1964-1965). *Technical Report Series* No. 117. IAEA, Vienna.

IAEA [1971] - Environmental Isotope Data No. 3 - World Survey of Isotope Concentration in Precipitation (1966-1967). *Technical Report Series* No. 129. IAEA, Vienna.

IAEA [1973] - Environmental Isotope Data No. 4 - World Survey of Isotope Concentration in Precipitation (1968-1969). *Technical Report Series* No. 147. IAEA, Vienna.

Izrael, Y.A., Stukin, E.D. [1967] - The Gamma Emission of Radioactive Fallout. AEC-tr-7100.

Karol, I.L. [1970] - Numerical model of the global transport of radioactive tracers for the instantaneous sources in the lower atmosphere. *J. Geophys. Res.*, **73**:3589.

Miskel, J.A. [1964] - Characteristics of radioactivity produced by nuclear explosives. In *Engineering with Nuclear Explosives.* TID-7695, pp.153-160.

Miskel, J.A. [1973] - Production of Tritium in Nuclear Weapons. In *Tritium* (eds. Moghissi, A.A. and Carter, M.W.). Messenger Graphics, p.79.

Morishima, H., Kawai, H., Koga, T., Niwa, T. [1985] - The trends of global tritium precipitations. *J. Radiat Res.*, **26**:283-312.

Nir, A., Kruger, S.J., Ligenfelder, R.E., Flamm, E.J. [1966] - Natural tritium. *Rev. Geophys.*, **4**:441-456.

Suess, H.E. [1969] - Tritium geophysics as an international research project. *Science*, **163**:1405-1410.

Unterweger, M.P., Coursey, B.M., Schima, F.J., Mann, W.B. [1980] - Preparation and calibration of the 1978 National Bureau of Standards tritiated-water standards. *Int. J. Appl. Radiat. Isot.*, **31**:611.

APPENDIX A

PRECIPITATION AND TRITIUM DATA FOR AUSTRALIAN SAMPLING STATIONS

	ADELAIDE	ALICE SPRINGS	BRISBANE	BUNDABERG	CAMPBELLTOWN	CAPE GRIM	CHARLEVILLE	CLAREDALE	DARWIN
LATITUDE	34 57S	23 49S	27 28S	24 52S	34 05S	40 41S	26 25S	19 35S	12 25S
LONGITUDE	138 32E	133 54E	153 02E	152 21E	150 49E	144 41E	146 17E	147 24E	130 52E
ELEVATION	6.0 m	545.0 m	38.0 m	14.0 m	75.0 m	94.0 m	303.9 m	10.0 m	31.0 m
1962	456 86.0 (41.0)	199	1050 87.7 (100.0)						1622
1963	621 40.2 (98.1)	119	1255 29.3 (96.7)						1344 24.7 (76.6)
1964	556 107.3 (98.0)	111 44.7 (86.5)	1224 35.4 (100.0)						2489 24.5 (99.1)
1965	338 55.6 (97.3)	82 63.6 (93.9)	1042 26.5 (99.1)						1554 32.8 (95.4)
1966	495 49.1 (100.0)	389 38.5 (83.8)	1112 20.3 (100.0)						1369 15.1 (99.9)
1967	254 49.8 (99.6)	236 21.9 (98.7)	1791 15.6 (99.8)						1626 13.2 (99.6)
1968	639 35.7 (74.3)	458 32.3 (100.0)	856 16.1 (100.0)						2121 13.9 (100.0)
1969	523 57.9 (99.8)	185 30.8 (98.9)	1044 23.4 (100.0)						1972 18.5 (20.1)
1970	419 25.5 (100.0)	175 31.2 (97.7)	1398 21.9 (90.4)	1234 13.6 (99.4)	669 37.1 (100.0)		358 31.8 (100.0)	1023 15.0 (100.0)	1146 14.2 (100.0)
1971	597 25.1 (100.0)	123 15.8 (69.9)	1427 13.8 (100.0)	1772 11.0 (100.0)	686 27.0 (99.4)		598 22.3 (93.1)	1382 9.6 (96.9)	1979 11.1 (100.0)
1972	363 26.3 (100.0)	271 13.2 (94.1)	1402 10.8 (99.8)	1286 8.0 (99.9)	866 22.9 (76.7)		2[illegible] 23.1 (93.2)	1043 7.0 (100.0)	1467 11.4 (99.8)
1973	626 16.4 (100.0)	448 16.0 (97.8)	1450 11.2 (100.0)	1883 8.2 (100.0)	841 13.6 (96.7)		761 11.1 (99.9)	1739 6.2 (100.0)	1661 7.4 (100.0)
1974	638 15.5 (100.0)	783 12.2 (93.0)	2171 7.1 (100.0)	1478 7.5 (99.4)	1181 10.7 (100.0)		487 12.0 (100.0)	1755 4.8 (96.3)	2643 6.2 (74.9)
1975	523 13.6 (100.0)	601 11.6 (94.5)	863 9.7 (100.0)	852 5.2 (100.0)	818 10.6 (100.0)		506 9.8 (99.4)	1480 5.6 (100.0)	1910 6.2 (82.3)
1976	368 10.8 (100.0)	551 8.5 (99.8)	1388 7.4 (99.9)	1455 4.9 (99.2)	993 8.8 (100.0)		547 7.9 (99.8)	1448 4.3 (98.4)	1563 5.5 (69.0)
1977	400 10.9 (100.0)	372 9.1 (97.0)	625 6.8 (100.0)	784 4.3 (100.0)	613 8.0 (100.0)		483 6.8 (99.2)	1067 3.5 (99.9)	2387 5.3 (100.0)
1978	500 10.2 (98.8)	429 9.8 (99.5)	1075 6.6 (100.0)	1138 4.6 (98.3)	1236 7.0 (100.0)		550 9.8 (77.8)	1082 3.9 (84.3)	1734 6.6 (100.0)
1979	512 8.5 (100.0)	307 7.6 (97.4)	721 5.5 (99.9)	477 4.7 (97.9)	425 8.3 (79.3)		272 8.0 (99.6)	1478 3.4 (98.7)	1197 5.5 (100.0)
1980	415 7.2 (99.5)	169 8.1 (78.1)	1035 5.2 (100.0)	843 3.9 (98.2)	448 7.7 (100.0)	778 5.2 (100.0)	419 7.3 (99.3)	789 2.8 (99.4)	1845 4.0 (100.0)

APPENDIX A (continued)

	ADELAIDE	ALICE SPRINGS	BRISBANE	BUNDABERG	CAMPBELLTOWN	CAPE GRIM	CHARLEVILLE	CLAREDALE	DARWIN
LATITUDE	34 57S	23 49S	27 28S	24 52S	34 05S	40 41S	26 25S	19 35S	12 25S
LONGITUDE	138 32E	133 54E	153 02E	152 21E	150 49E	144 41E	146 17E	147 24E	130 52E
ELEVATION	6.0 m	545.0 m	38.0 m	14.0 m	75.0 m	94.0 m	303.9 m	10.0 m	31.0 m
1981	537	310	1481	973	904	854	427	1326	2164
	6.9	6.6	4.5	3.4	5.9	5.6	6.0	3.3	3.7
	(99.8)	(97.4)	(100.0)	(100.0)	(99.1)	(98.0)	(99.5)	(96.2)	(99.9)
1982	286	294	1088	985	413	573	245	400	1495
	5.9	6.3	4.7	3.6	5.4	4.4	6.5	4.2	4.6
	(99.6)	(100.0)	(99.8)	(96.9)	(100.0)	(100.0)	(96.7)	(97.0)	(99.9)
1983	576	549	1471		838	680			1885
	6.6	5.5	4.2		5.2	4.7			4.1
	(99.7)	(99.6)	(100.0)		(100.0)	(94.6)			(98.3)
1984	390	289	1041		916	736			1949
	5.6	5.5	3.9		5.3	4.2			3.2
	(100.0)	(99.3)	(97.2)		(100.0)	(100.0)			(100.0)
1985	379	121	1142			776			1233
	5.7	5.3	4.0			4.3			3.3
	(99.2)	(98.3)	(100.0)			(100.0)			(99.9)
1986	482	394	779			781			1738
	5.8	5.1	4.3			4.4			3.6
	(99.8)	(100.0)	(100.0)			(100.0)			(94.1)

Years 1962 to 1969 Data from Environmental Isotope Data : World Survey of Isotope Concentration in Precipitation

Years 1970 to 1986 Data from Australian Atomic Energy Commission Tritium Lists.

1980 415 Precipitation in mm

7.2 Yearly weighted mean for tritium (T U), weighted by the total amount of Precipitation

(99.5) Percentage of the total precipitation for which tritium data are available to calculate the weighted means.

APPENDIX A (continued)

	HOBART	LONGREACH	MACKAY	MELBOURNE	NARRABRI WEST	PERTH	SYDNEY	TOOWOOMBA
LATITUDE	42 53S	23 26S	21 07S	37 49S	30 20S	31 56S	33 52S	27 35S
LONGITUDE	147 20E	144 17E	149 13E	144 58E	149 45E	115 58E	151 12E	151 56E
ELEVATION	55.2 m	191.0 m	6.0 m	34.7 m	212.0 m	20.0 m	92.0 m	675.0 m
1962				588 17.2 (42.7)		713		
1963				746 47.1 (98.5)		998 24.8 (97.8)		
1964				706 51.9 (89.1)		976 30.4 (78.6)		
1965				592 55.2 (99.8)		942 33.2 (93.4)		
1966				683 55.5 (100.0)		415 33.7 (98.8)		
1967				334 55.0 (100.0)		1036 21.4 (100.0)		
1968				516 40.7 (100.0)		931 21.8 (99.6)		
1969				627 38.8 (100.0)		574 19.3 (100.0)		
1970	781 29.7 (100.0)	285 23.4 (88.0)	1554 8.8 (100.0)	803 38.4 (100.0)	708 37.5 (66.1)	845 20.6 (99.9)	1028 30.5 (100.0)	812 22.8 (100.0)
1971	752 32.1 (100.0)	469 20.3 (74.4)	1699 9.1 (100.0)	775 35.1 (100.0)	748 37.1 (42.4)	774 16.3 (89.3)	988 22.8 (87.8)	972 18.9 (97.4)
1972	451 24.9 (100.0)	305 18.2 (99.3)	1741 6.9 (99.7)	564 26.8 (99.8)	657 23.4 (91.6)	576 12.6 (99.8)	1307 18.1 (99.8)	915 16.0 (100.0)
1973	604 16.4 (100.0)	606 9.8 (99.7)	1767 5.0 (100.0)	819 20.1 (96.3)	796 17.0 (82.5)	915 11.2 (100.0)	1388 14.7 (100.0)	1020 12.1 (100.0)
1974	1014 16.7 (100.0)	564 7.7 (99.2)	2307 4.0 (88.4)	803 17.0 (100.0)	576 14.0 (75.2)	875 8.9 (73.3)	1452 8.9 (100.0)	1256 10.1 (100.0)
1975	827 13.9 (100.0)	457 8.8 (99.6)	1710 4.3 (100.0)	710 18.7 (100.0)	663 12.3 (99.7)	692 9.3 (99.9)	1293 10.8 (97.8)	1202 10.7 (99.3)
1976	665 9.6 (100.0)	467 6.3 (100.0)	2248 3.8 (99.4)	503 17.0 (100.0)	755 9.2 (99.2)	710 8.0 (100.0)	1784 7.8 (100.0)	1164 7.3 (100.0)
1977	495 9.7 (100.0)	548 6.1 (90.9)	1534 3.6 (99.5)	605 11.4 (100.0)	910 9.0 (84.8)	615 6.7 (99.7)	925 7.9 (100.0)	868 6.3 (98.6)
1978	608 8.4 (100.0)	461 8.1 (99.3)	1409 3.7 (100.0)	867 11.2 (100.0)	872 9.5 (87.7)	823 6.5 (100.0)	1499 7.5 (100.0)	1234 7.4 (100.0)
1979	391 9.4 (99.5)	295 6.1 (98.6)	2483 3.6 (100.0)	543 11.1 (100.0)	483 10.3 (63.6)	568 5.2 (100.0)	814 7.8 (100.0)	920 6.4 (100.0)
1980	465 7.0 (100.0)	598 6.2 (100.0)	1183 3.2 (100.0)	644 8.9 (100.0)	486 8.1 (41.2)	700 5.1 (100.0)	736 5.7 (100.0)	954 6.7 (100.0)

APPENDIX A (continued)

	HOBART	LONGREACH	MACKAY	MELBOURNE	NARRABRI WEST	PERTH	SYDNEY	TOOWOOMBA
LATITUDE	42 53S	23 26S	21 07S	37 49S	30 20S	31 56S	33 52S	27 35S
LONGITUDE	147 20E	144 17E	149 13E	144 58E	149 45E	115 58E	151 12E	151 56E
ELEVATION	55.2 m	191.0 m	6.0 m	34.7 m	212.0 m	20.0 m	92.0 m	675.0 m
1981	548 6.3 (100.0)	452 4.1 (90.5)	1359 3.2 (93.7)	602 8.1 (100.0)	547 5.3 (75.0)	791 4.5 (99.9)	1038 5.0 (100.0)	1479 5.3 (100.0)
1982	398 5.4 (100.0)	173 6.5 (99.4)	980 3.0 (99.7)	422 6.9 (100.0)	406 5.8 (93.3)	665 5.6 (100.0)	838 5.1 (100.0)	896 6.2 (100.0)
1983		381 4.2 (87.1)	1382 3.0 (100.0)	612 8.2 (99.8)	973 6.1 (100.0)	721 4.5 (100.0)		
1984		379 4.1 (96.3)	821 2.8 (100.0)	563 6.5 (100.0)	888 5.5 (98.9)	748 4.1 (99.9)		
1985		272 5.1 (93.4)	1626 2.7 (100.0)	679 6.4 (99.1)	478 6.9 (60.5)	620 4.4 (94.8)		
1986		421 4.5 (98.1)	1585 2.6 (100.0)	487 5.3 (65.7)	465 5.4 (89.0)	901 4.4 (99.8)		